THE MULTIMODAL MIND: HOW THE SENSES COMBINE IN THE BRAIN

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Multiple convergences of the senses?

Is the brain specially tailored to multi-modal function? This would be natural, since organisms live in a world of multimodal objects. One would suppose that multimodal processing would not be an occasional add-on, but would be inherent in brain activity from the start. Surprisingly, the traditional model of the brain implies the opposite. It implies that after unimodal information is identified, that it requires an extra step to conjoin modalities, coordinate them and train them. Because this extra step is costly, it should be difficult for simple brains, and should take human children many years of brain maturation to accomplish. None of this is the case, but I will sketch it, dismiss it, and present an alternative view.

The classical notion proposes an organization that I have characterized as constituting the "wasp-waist brain". It assumes a hierarchically organized brain, rather like a business, military or political organization; information enters the cerebral cortex of the brain at multiple relatively peripheral locations and becomes integrated into fewer and more complex packages through multiple sequential convergences. Finally the information flow converges on what William James called the "pontifical cell". This endpoint of information flow would then be the only brain structure that is fully informed, and

therefore qualified to make all the decisions, that is, to pontificate. This nineteenth century concept has outlived its usefulness, but still persists in some quarters. What is the pontifical cell? In effect it is homuncular, an inner eye that observes the input displayed on the functional equivalent of a screen (the Cartesian Theater – Dennett and Kinsbourne, 1992). At the word "homunculus", philosophers and neuroscientists routinely throw up their arms: "We don't believe in homunculi, or feminculae, for that matter!" However, among them are many covert Cartesians, who do, without calling it that. Even the supreme neurophysiologist, Sir Charles Sherrington (1934), ventured the intuitively appealing claim that "the mental action lies in that part most deeply recessed from the outside world that is furthest from input and output." He assumed a hierarchical pyramid of unidirectional centripetal information flow, with the buck stopping on a virtual executive desk somewhere unapproachably deep in the core of the brain. However, though Sherrington had clarified the organization of the brain stem and spinal cord, he never did penetrate deep into the forebrain. Had he done so, he would have realized that no such module for "mental action" exists. The fact that neuroanatomy does not feature anything remotely like this kind of organization amounts to a "non-existence proof" (Kinsbourne, 1998). A non-existence proof indicates ways in which the brain may not work.

The wasp-waist pattern of organization would have implied the following for multimodality accomplishments: The portals of entry for any two modalities being separate within the nervous system, the modalities have to be conjoined at a convergence zone, which is a third place. There would be one brain area for identifying a visual stimulus, one place for identifying an auditory stimulus, and a third place to do the extra

work of recording their association. Danish investigators, Roland et al. (1977), performed an experiment for other reasons, which, though they did not realize it, addressed this issue. They determined which brain areas were activated in response to a flash, a click, and a flash as well as a click. The flash activated the visual area. The click activated the acoustic area. The two together activated both the visual and the acoustic areas, but no additional "cross-modal" area lit up. The hypothetical point of confluence didn't light up, and I don't believe there is such a place. If there is not, then how does cross-modal integration work?

Instead of a brain that is patterned as multiple convergences toward and divergences from a point, the functional anatomy of the brain reveals a completely different architecture. That architecture should be considered in the following context (elegantly presented by Braitenberg, 1977). The brain contains 10 (11) neurons that form 10 (14) synapses. Between any neuron and any other neuron there are at most four levels of synaptic separation (Braitenberg and Schuz, 1992). So the system is very highly linked. Yet the system is very highly differentiated, in that many different parts each contribute different components to overall cognition. I do not believe that cognition and the phenomenal experience that inheres in it, is usually assembled out of many parts against a blank slate background, a view that I call assembly theory. Instead, I invert the motto of my country of adoption, Ex Pluribus Unum, to Ex Uno Plures. The domains of awareness, perception, intention, experience, do appear to be seamlessly coordinated. However, that unity is not an assembled collage, but emerges from a rudimentary unity that is differentiated out so as to represent the specific details of the moment, from the preceding

brain/cognitive/experiential state that now serves as background (Kinsbourne, 1988, 1996).

Parallel reciprocal processing and modality integration

Counter to the traditional image of the brain as a unidirectional information thoroughfare, when cell stations in the brain connect, the traffic is almost always bi-directional. The traffic is not in one direction, with a little feedback, either. Areas interact equally in both directions, directly reciprocally, or indirectly by looping across several cell stations, so that the neural traffic reverberates through its starting point. The forebrain is overwhelmingly an arena of reverberating reciprocal influence. Why this is so becomes intelligible when we reflect that neurons are not passive structures that spring into action only when stimulated or switched on, but active structures that fire at a base rate all the time. Neurons are always signaling to one another. Periodically they fire at a greater rate if they become involved in the dominant action of the moment, and then, even fractions of a second later, fire less frequently when they again lapse into obscurity. This continual neuron-to-neuron chatter greatly outweighs the activity of neurons that influence, or are influenced by, outside events, or the state of the body. More than 95% of the neurons in the cerebral cortex signal exclusively to other neurons in the cerebral cortex. This is not the type of organization that one would expect if the brain existed primarily as an input-output mechanism in order to control the actions of the body, although it does do that. Rather, it suggests a self-sufficient and self-organizing structure, which keeps busy by itself at a comfortable level of activation. In order to maintain its stability, it only once in

a while has of necessity to respond to the outside world or forestall it, basically to exploit it, repel it, or otherwise deal with it, after which it resumes its own internal chatter.

Everyone directly experiences this perpetual neuronal chatter. Consider that from the moment you wake to the moment when you fall asleep you chatter internally, mostly as inner speech, sometimes in images. You can't help but think and think because the neurons can't help but fire. It is not because you've necessarily got something to think about, since most thoughts do not appear to be of any particular use or adaptive value, but because continual neuronal interaction is of the essence in the waking brain. The forced thinking is the subjective aspect of the perpetual interactive chattering of the neurons of the brain. The brain does of course have spectacular control properties, but what it primarily controls is its own state, directly, or indirectly by controlling behavior. It is a self-stabilizing homeostatic device. There shouldn't be too much activity; there shouldn't be too little.

When it receives input, the following options are available to the human brain. One, it habituates the information out. The input is neutralized at the point of entry. The brain simply takes no account of it, and the brain state is uninfluenced by the information. This happens with most input most of the time. It is filtered out as expected, adaptively trivial, and uninformative. If the information is significant enough to override habituation, the next option is to accommodate to it. The output is registered, and expectations are correspondingly adjusted. If accommodation isn't sufficient, because the event is novel or appears to threaten adaptation, then the brain has to deal with the stimulus or withdraw from it (Duckworth et al., 2002). To do so it has to activate the body's motor capabilities,

to turn away from the stimulus, to remove or manipulate, disarm or otherwise neutralize it. The fourth remaining option is for the human brain to forestall the change, if it promises to have significant destabilizing force. The brain forestalls the expected threat to property by instructing the body to set the burglar alarm. It forestalls the impending hunger pangs by staying very close to food, in North America an easy task. It anticipates future needs and threats by reducing them proactively, thereby assisting its own self-stabilizing efforts.

What is the architecture that makes the recursive heterarchical organization feasible? Visual information that arrives at the first cortical relay for vision, area V1, is steered into two parallel streams that transmit the activation centripetally toward the core limbic system of the brain. A ventral stream seeks to identify what is perceived, and a dorsal stream determines its location, or in a more practical sense determines "how I would get there". The two streams address the "what" and "where", or the "what" and "how". This dichotomy in vision doesn't exist in other modalities. We are exceptionally skilled both at visually characterizing the nature of things, their pattern, their identity and also we have excellent spatial resolution in terms of the visual framework. However, determining what and where calls for quite different underlying rhythms of neural firing. So it makes engineering sense to entrust different parts of the brain to the identifying of the exemplar and locating it in space. It is as if visual identification and visual locating were different modalities. For any visual display, two programs run concurrently, one program identifying and one program locating, and when they both accomplish their goal that is the percept. They don't then first need to come together to a decision point. The fact that any part of the brain comes to a conclusion about what it's processing is sufficient to

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make it part of our experience. So the ventral part will represent "a person" and the dorsal part will represent "to the left" and those two standing patterns will be the experience of a person to the observer's left. Streams are better called "trends" (Pandya, Seltzer and Barbas, 1988), because unlike flowing water, information passes in both directions. The two trends are held separate because identifying and locating are qualitatively very different mental operations, and are best kept apart until completed, since they might otherwise interfere with each other by neural cross-talk.

The brain is organized as a recursive global network, with three levels of embedding. The cortical neurons line up in radially oriented columns that are orthogonal to the cortical surface. Microcolumns of neurons cluster into macrocolumns of neurons. These aggregate to form processors, which in turn are lined up as trends, each trend being a set of four processors in linear sequence (Pandya et al., 1988). In addition to the trends, there are a number of relatively small polymodal areas in the cortical grey matter. Their specific roles in behavior are uncertain. But each area represents no more than three modalities. No polymodal area is in a position to pontificate. The sum total of trends constitutes the bulk of the global cerebral network. Information from the periphery speeds centrally along these linearly, sequentially, organized units. At the level of each unit there are lateral connections to other trends that subserve other modalities, at the same level of their organization. All connections, anterior-posterior and lateral, are bi-directional. The upshot is that there is lateral integration from the start of input processing, offering ongoing multimodal integration, not solely as an afterthought, after unimodal processing is completed.

Expectation and anticipation

The input modalities are integrated early on, as are the efferent mechanisms. Their representations extend from the motor cortex at one end of the trend to the prefrontal cortex at the other end. The motor cortex is the final cortical relay prior to output, as V1 is the first cortical relay for visual input, and the organization on the output side mirrors that on the input side. The deep end of each trend is anchored in the limbic system. This bi-directional highway permits expectation to meet up with perception, and initiated action to feed back to preparation. A wave of neural signaling traveling in one direction can be intercepted or even anticipated by a wave traveling in the opposite direction. From the limbic system, which is the effective core, the neural surrogates of needs, desires, evaluations, hopes and aspirations radiate out toward the periphery, to meet and qualify the input with the antecedent anticipation, expectation, evaluation and preparation.

We are not cameras. We do not traverse the world as blank slates, on which the environment presses its information. When organisms move, they generate perceptual change. Braitenberg (1977) remarks: "The capacity to predict the future is an essential attribute of the brain. Normally, the sensory input and the internal prediction are inextricably mixed" (p. 120). We make our way through the world with continually modified expectation, expecting a space, a texture, certain kinds of occupants and not others. When I enter a lecture hall, I do not know who specifically would be there, and where in the space they would be, but I expect a room of commensurate dimensions. I expect tables or desks, and chairs. I expect people. I do not know which people, or where they would be sitting or what their hairstyles would be like, but I expect people. My

expectations are not specific percepts, that is, they are not hallucinations. They are generic. They have to stop short at general categories to be of use. That means that the waves toward the outside, the centrifugal ones, must stop short of the exact definition offered by V1, where anticipatory images would be too specific. One would be unlikely to recognize anybody if he pictures them from one specific angle, in one posture, with one hairstyle, particular garments and a specific expression on their face. Probably no one ever looks exactly the same on any two occasions. On viewing objects one attends to nodes and patterns that carry maximal information, and discounts incidental and uninformative details. The expectation has to be sufficiently generic to accommodate the degrees of freedom of all the perceptual dimensions that vary unpredictably in the real world, without altering the identity of the object in view. So if I saw, within limits, fewer people, more people, older ones, younger ones than expected, that would not interrupt the traffic in my brain, or alert it to a novel circumstance. However, a giraffe in one seat and a gazelle in another, with pencils in hoof and open notebooks before them, would be outside my expectation. Whatever neural activity is going on, whatever my train of thought, would abruptly halt. My right hemisphere would light up in response to a novel event, and I (that is, my brain) would review and rethink the situation, and strive to make alternative plans.

Amplified activation for multimodal processing

Attending is selectively amplifying activation at the level of the brain. Selectively attending to one of two stimuli, or to a location to which a stimulus is then projected, enhances the activation that the stimulus elicits. Now consider the implications for

multimodality functioning. The lateral connections between input channels (side-to-side) implement sensory-sensory connection, the saggital ones (front-back) implement sensory motor connections. Coincident stimuli from two modalities disproportionately enhance reaction to a target stimulus, in humans, animals and even in recordings from single neurons (discussed by Jiang, Jiang and Stein, 2002). These connections become active very early (Wallace and Stein, 1997). How does the brain react to simultaneous presentation of stimuli in two different modalities, as indexed by the method of evoked potentials? How much activation results from each stimulus and where in the brain is it? Each stimulus by itself generates a certain amount of activation in its primary receiving area. By being presented together, they engender more activation in both their receiving areas. This renders them more salient, and therefore more likely to control behavior, and increasing their chances of becoming included in awareness. Subsequently, multisensory input is coded by individual neurons in prefrontal cortex, where some neurons respond selectively to coincident visual and auditory stimuli (Aou et al., 1983) or to visual, auditory and tactile stimuli (Tanila et al., 1992). A single neuron cannot determine how the modalities of its input are combined, but merely that a particular stimulus has the attributes for which it is specialized, that is, that it incorporates two, or three, particular modalities. So, they fire to amplify the activation that stimuli occasion simply by being multisensory. In the case of prefrontal neurons, the firing of multisensory neurons is dictated by motivational factors. If stimuli in either of two or more modalities are conditioned to the same reward, corresponding multimodality neurons fire (Watanabe, 2002). These are ways by which the brain gives priority to multisensory input.

Saron et al. (2001) recorded patterns of brain electrical activity from 128 surface scalp electrodes during a reaction time task, over successive 10 msec. epochs. The observer sits with his finger on a response button. A flash is presented from the right or from the left. In the condition of interest to this discussion he doesn't even have to respond. It's the simplest condition. For example, 78 milliseconds after a flash, when the stimulation came from the left field, activation is recorded over the right back of the head, that is, the right occipital lobe. There is as yet no discernible transfer of activation across to the contralateral occipital lobe. Yet the motor areas have already lit up, on both sides. There isn't a continuous flow of information from back to front, which finally converges on the motor areas. There is a privileged connection between the input analyzer and the potential response mechanism, even when no response is called for. This is a privileged stimulus-response multimodality connection. It's preformed; it doesn't take extra work. After all, in the real world the brain is not dealing with attributes, but with things and events. The brain specializes in things and events. It starts with a multimodality assumption. If desired, the object or event can subsequently be broken down and analyzed into its constituent parts. That comes later.

Multimodal expert systems

In a very simple nervous system what you see is not free floating modalities that haven't been cobbled together, but on the contrary, multimodality expert systems. A behaviorally humble animal may have just one thing that it's good at. In such an instance, one might think, if it's that good a problem solver, why can't it conquer the world with its intellect? Here's why. Consider a large Polynesian fish, which feeds on smaller fish in shallow

waters with a mud bottom (Kaufman, personal communication). The little fish emerge from their shelters in holes in the mud to feed. The big fish is waiting to eat the little fish. How does he best accomplish this? I have asked my students "If you were the big fish, what would you do?" and so far no one has offered the correct answer, that is, the tactic that works for the big fish. To snap at the greatest possible rate would still leave time for most of the little fish to dart back into their holes. No. Exhibiting formidable impulse control, he smoothes over the mud with his body to block all the holes, so the little fish can't go home to their burrows. Then he picks them off one-by-one, which is pretty smart. The problem is that this is the only thing that this big fish is smart about. The expertise is nested within a functionally "encapsulated" module, and is unavailable for any other problem solving. The machinery is in place, but it applies to just that one situation. How are humans different? It's not that they are necessarily smarter in each specific situation. It's that they can generalize. In humans the boundaries between expert systems break down. Though incomplete, and subject to great inter-individual variation, the breakdown of the "modularity" of expert systems has a remarkable unforeseen consequence (Rozin, 1976). Once the logic that was initially evolved for a particular purpose becomes available to other systems there's no knowing what else it's going to be used for. That is how the human species has been able to accomplish what it has. We now apply logic acquired in limited settings to astrophysics and blowing off the heads of other people, and we are very good at doing these things. Of course that is also why, while our brains and bodies work rather like clockwork at the systems level, we are so fallible when it comes to behavior. An expert system works perfectly, and never goes wrong. At the subpersonal level our neurons work with spectacular efficiency. Even the most inexpert and blockheaded politician's neurons work very well. It is the vicissitudes of generalizing

expertise that underlie stupid behavior. We have too many unforeseen contingencies to deal with, to which existing expert programs are not fully applicable.

An extreme instance of sensorimotor integration appears to be offered by the much discussed "mirror neurons" (Rizzolatti et al., 1996). Microelectrode readings in primate premotor frontal cortex reveal neurons that fire both when a meaningful act is perceived, and when it is intended and performed by the observer himself. The animal sees another one grasp something, or itself initiates the grasp. Janus-like, the mirror neuron fires on both occasions. Impressed by this show of unification within the small constituent units of the brain, some have credited mirror neurons with vital roles in human language, empathy, theory of mind (e.g., Stamenov and Gallese, 2002), although, ironically, we do not know whether humans have mirror neurons, and monkeys, who do, are rather short on these attributes. A more prosaic account would argue that mirror neurons do not integrate the comparable input versus output states, but instead, fail to distinguish between them (Kinsbourne, in press). Perceiving an action entails representing it, and marking it as performed by the other. Intending it again entails representing it, but this time marking it for self. It appears that mirror neurons are involved in the representing, and other parts of the brain mark the representation as pertaining to the self, or to someone else. As I have already noted, the brain has little trouble in forming close connections between modalities, without needing to economize by having neurons do double duty. Neurons are not in short supply in the brain. Rather, I think that the notion that a single neuron can pontificate about such complex matters as empathy is captivating to the closet Cartesians among us.

This meeting is particularly concerned with multimodality in language. A multimodal example would be the ability to process, in conjunction, verbal contents, intonation, facial movements and expression in determining whether a speaker is telling the truth. We are allegedly so good at this that evolutionary psychologists credit us with a "cheater detection" module. However, so many cheaters go undetected that one might question the expertise, or even the existence, of such a module. Perhaps there is an "arms race" between cheater detection and another, "dissembling" module, and perhaps the latter currently has the upper hand. Perhaps all this demonstrates is how vacuous it is to partition human skills into separate aggregates of "massive modularity" (Sperber, 2001). We can import logic from one activity to another. We do not need a separate module for each stunt.

Simultaneous activity in different modes.

In a parallel and nested neural system, how would one concurrently sustain two activities in different modalities? If the activities are compatible with each other they would most smoothly combine if represented close to each other neurally, but there is a cost, or at least a risk. They may collapse into each other and become one. Pianists learned to play different melodies, one with each hand, at the same time. Then they hummed along with one the melodic line and rhythm generated on the piano by one hand or by the other (Kinsbourne and Hicks, 1978). They could do all that, but when they were humming with one hand, the other hand's rhythm would collapse into the dominant rhythm. That is the cost of having things too like each other; they may collapse and merge into a less differentiated whole. This is also the problem in problem solving. In order to solve a

problem, you have to reject the obvious solution or otherwise it wouldn't be a problem, and think of a second alternative solution. If your brain isn't big enough, its neural activity will just collapse back into the obvious solution and you are stuck with the wrong answer. In contrast, if you want to do two incompatible things at the same time, the problem is that they may interfere with each other, not that they collapse into each other. To minimize this one needs as wide as possible a separation in "functional cerebral space" (Kinsbourne and Hicks, 1978). Multiple synapses between the two patterns of activation would minimize the cross talk between them. The balancing act that the brain has mastered is to hold activation at levels appropriate for the combinations of activities that are called for. In the piano experiment, a successful balancing act between unrelated playing by the two hands was thrown into disarray by amplifying the neural patterns that underlie one of the competing melodies cross-modally, by humming along with it. A simpler example is right/left balance. There is an opponent system by means of which we attend to the right or to the left. Each hemisphere activates the superior colliculus inferior to it. The more activated superior colliculus directs the attentional vector toward the opposite side. If both colliculi are equally activated, the vector resultant is straight ahead. If they are out of kilter, then attention drifts sideways. The syndrome of unilateral neglect results from such an imbalance in lateral directed attention (Kinsbourne, 1987).

Consciousness and personal interaction

I see the cortex as an activation manifold, a thing of peaks and valleys of activation. Recent findings of Hutchinson et al. (1999) by use of functional magnetic brain imaging, illustrate this view. The brainscape changes continually in an eye-blink, by virtue of the

traffic of the neurons. The contents of our experiences are heavily weighted towards the peaks of activation, whereas the troughs contribute rather little. However, our experience is always constituted of the configuration of the whole network. There isn't a particular central location where consciousness happens, but rather each part of the brain incorporates a potential consciousness of what it does. When one separates the two cerebral hemispheres, one finds on the one side the awareness of that which the left hemisphere does, including an awareness of inner speech, and on the other side what the right hemisphere does, including a rather subtle awareness of spatial locations, emotional tones and so on. A lesion in a single place cannot eliminate consciousness. One has to remove virtually the whole cortical mantle. Removing part of it restricts the range of consciousness, its richness, but does not abolish the fact of consciousness.

Having so far discussed the "selfish brain", concerned solely with its own well-being, I conclude by applying the question of multimodal coordination to social interaction, beginning with basic dyadic interaction entrainment between interacting individuals (Jaffe et al., 2001). I distinguish four levels of dyadic communication. The primary and fundamental result of two people engaging, seen in "pure culture" between mother and child, or, as I prefer to say, father and child, is affiliation. Both are motivated to engage each other visually, acoustically, physically. Human babies enjoy looking at people, reacting to people, eliciting responses from people, regardless of their content (Kinsbourne, in press). It's an emotional affiliation and that's the first thing that language, and preverbal interaction, do. You may wonder, as I have, why it is that we spend so much time talking irrelevant nonsense: "Oh, how are you today? Isn't the weather awful?" Well, it gives people great satisfaction, and the older they are the more

satisfaction they derive from telling each other things they already know: "Oh, you remember how Aunt Mary fell down the stairs?" or something similar for the umpteenth time, because they have few alternative options for action. There is something emotionally compelling about the interaction as such. The second more general purpose of language is to orient the other to your train of thought, your mental state, and vice versa. The baby says "da" and if you are smart, you'll say "da" and you can trade "da"s with the baby very satisfactorily. Great friendships are made this way, perhaps even now, as I am orienting my audience to the way I think about things, with the use of language. The third use of language is interrogatively, imperatively: "please give me this", and so on, and the fourth is information exchange. All of this is a confluence of modalities. I suspect that in this conference we will see quite a few examples of all the levels I have just talked about.

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